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Heat Treatment Study II

by

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## INTRODUCTION

Superalloy systems have proven to function in the hostile regions in aerospace systems such as the SSME and gas turbine engines for jet aircraft. The metallurgical properties of superalloys which allow such materials to perform in these extremely harsh environments are not completely understood even after many years of research in developing many new and useful superalloys. Much research is still being conducted to either understand superalloys or to improve their properties even more.

Consequently much research in characterizing superalloy ~~is~~ systems is concerned with processing many samples with a particular process, such as casting, forging or directional solidification; then following with a particular heat treatment, and then destructively testing a large enough sample size to determine the result of that process statistically. Such is the nature of this research task.

The primary property of superalloys which has been studied in this work has been the microstructure variation which results from modifications in processing. The principal microstructural variables of superalloys are the precipitate amount and its morphology, grain size and shape, and carbide distribution. Aside from the variations in composition, the process selection provides the largest affect on a superalloy's performance characteristics. For a given composition, property advantages and disadvantages exist due to microstructural differences created by differences in processing of the material.

Nickel based superalloys, such as the MAR-M246(Hf) studied here, typically consist of  $\gamma'$  dispersed in a  $\gamma$  matrix, where the strength is a function of the volume fraction  $\gamma'$ . The inherent strength capability of such superalloys is controlled by the intragranular distribution; however, the usable strength in polycrystalline superalloys is determined by the condition of the grain boundaries. This is especially true in the case of grain boundaries which are affected by carbide phase morphology and distribution.

For example, satisfactory properties are achieved by optimizing the  $\gamma'$  volume fraction and morphology in conjunction with securing a dispersion of discrete globular carbides along the grain boundaries. Cellular carbide at grain boundaries increases surface area and drastically reduces rupture life even though tensile and creep strength may be relatively unaffected.

Strength increases as the volume fraction of  $\gamma'$  increases and creep rupture strength is directly related the volume fraction of fine  $\gamma'$ . The size of  $\gamma'$  can also be influenced by cooling rate as well as time at various aging temperatures. Since the grain size also affects superalloy strength, there is an obvious need to control all these morphological parameters. Consequently the study of directional solidification and heat treats on superalloys provide an enormous area of research for the development of useful superalloy systems.

The directional solidification, heat treatment, and analysis of MAR-M246(Hf) performed in this study continues previous work

performed by UAH. The goal of the research is to improve the mechanical properties of the alloy in order to extend its useful life in the operating environment of the SSME, thereby resulting in reduced flight costs.

## PROCEDURES

The heat treatment procedures for superalloy MAR-M246(Hf) is usually to perform a solution treatment followed by cooling to room temperature, then an aging treatment, followed by cooling to room temperature. The solution treatment homogenizes the alloy and places the  $\gamma'$  strengthening phase back into solid solution in the matrix. The aging treatment then is performed to control the size, shape, and amount of  $\gamma'$  for optimum properties. In the normal experiments, the alloy is held at  $1221 \pm 6^\circ\text{C}$  solution temperature for 2 hours  $\pm$  20 minutes and aged for 24 hours at  $871 \pm 14^\circ\text{C}$ . Alternate heat treatments for equiaxed, as cast specimens were studied in this work. A sample matrix of 42 variations in the heat treatments were processed, as well as different directional solidification parameters. Variation in temperature and times for both solution and aging were performed. Other temperatures used included  $1140 \pm 10$ ,  $1175 \pm 10$  and  $1200 \pm 10^\circ\text{C}$  for the solution treatment and  $760 \pm 10^\circ\text{C}$  for the aging treatment.

The processed samples were prepared for examination by cross-sectioning, mounting, and then polishing. The eutectics became visible upon etching with Adler's etchant. Photomicrographs were made of the microstructure and volume fraction analysis was

performed on the interdendritic  $\gamma$ - $\gamma'$  eutectic. Since the  $\gamma'$  structure is only distinguishable at higher magnifications, replicas were made from each sample and characterized with the Transmission Electron Microscope. The photomicrographs were taken at 4000X and volume fraction analyses of primary  $\gamma'$  and aged  $\gamma'$  were performed.

## **HEAT TREATMENT RESULTS**

A Weibull analysis of the heat treatment samples was performed by the M&P Laboratory and the results indicated that the critical variable in the  $\gamma'$  formation appears to be the solution treatment temperature. The analysis performed here indicated that at temperatures less than 1221°C, the  $\gamma'$  particles which precipitated did not all redissolve. These  $\gamma'$  particles coarsen during aging, resulting in large incoherent particles. However, the data overall indicates that slightly improved fatigue properties were obtained for the reduced solution treatment of 1 hour at 1221°C with standard aging.

## **Cooling Rate Studies**

The effect of cooling rate solution treatment was undertaken during this phase of the research. By increasing the cooling rate from 60° F/min to 150° F/min we were able to improve the yield strength of PWA1480 by 20 ksi and the ultimate strength by 5 ksi. TEM analysis is planned to be performed at a later date.

The data from the above experiments is quite voluminous and currently is in the possession of Ms. Diane Schmidt on M&P Laboratory.

## **DIRECTIONAL SOLIDIFICATION RESULTS**

Magnetic field directional solidificational experiments for fields greater than 5 kilogauss were not completed because the core lead wires failed due to intense vibration induced by the furnace core ac current in the presence of magnetic fields greater than 5 kilogauss. DC current was tried but would not properly melt the alloy specimens.

Electric field directional solidification experiments were hampered because the intense heat produced at the heater connections thermally stressed the conducting leads which kept shorting out. Hence a sufficiently large amount of material for analysis was not able to be produced. Some of the smaller samples processed did show some interesting microstructural changes. Quantification of these changes are planned for a later date. Robert Bond, the student working on these projects, will possibly be included in a patent disclosure with Ms. Schmidt and other M&P Laboratory research personnel concerning improvements to existing NASA patent applications.

## **ACKNOWLEDGMENTS**

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